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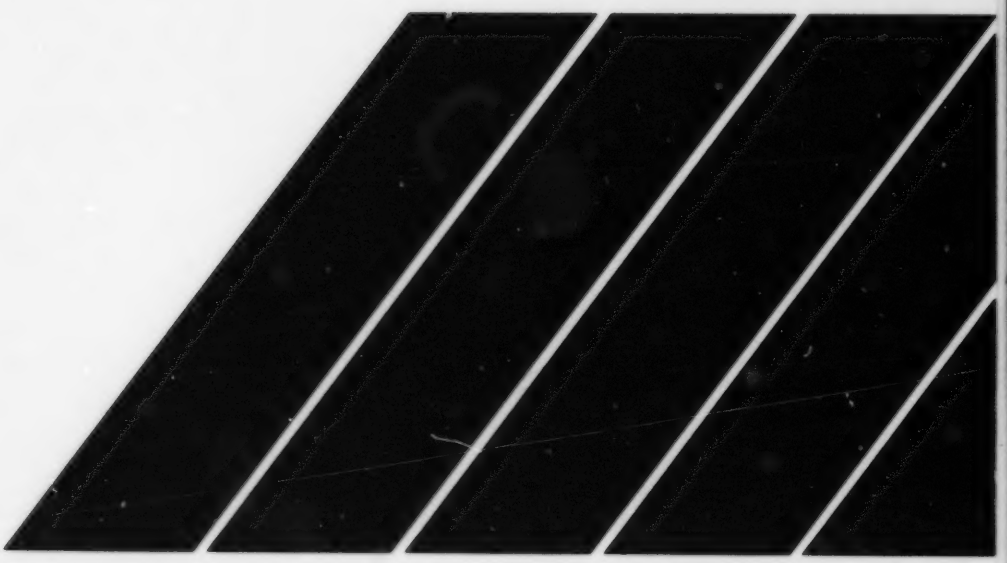
THE ECONOMICS OF PARTICULATE POLLUTION ABATEMENT TECHNOLOGIES FOR WOOD-WASTE-FIRED COMBUSTORS



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THE ECONOMICS OF PARTICULATE POLLUTION ABATEMENT TECHNOLOGIES FOR WOOD-WASTE-FIRED COMBUSTORS

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RÉSUMÉ

La production d'énergie utile à partir de déchets solides de bois, bien qu'elle ne contribue pas grandement à la demande globale d'énergie à l'heure actuelle, pourrait avoir un impact important dans les régions du pays où les coûts associés à l'énergie sont traditionnellement élevés et où les sources de déchets de bois sont abondantes.

Toutefois, l'éloignement des installations de conversion des déchets de bois existantes et éventuelles ne les dispense pas de devoir produire des niveaux acceptables d'émissions et tout examen de la rentabilité d'un projet doit tenir compte des coûts relatifs à l'atteinte de ces niveaux.

L'objectif de l'étude est de quantifier l'impact de l'équipement nouveau et amélioré de réduction des particules (ERP) sur la rentabilité des systèmes de combustion de déchets de bois nouveaux ou existants. Les résultats de cette étude seront utilisés par EMR dans le cadre de ses efforts visant à accroître l'utilisation des déchets solides de bois, en tenant compte des facteurs économiques et de l'environnement.

En raison de la diversité des chambres de combustion et des technologies antipollution qu'on peut actuellement de procurer et dont on fait déjà usage, une évaluation globale s'avérerait plus complexe à réaliser que prévu. On retrouve un exemple de cette complexité dans le domaine de la modernisation des installations de combustion existantes par l'installation de matériel d'épuration. A cause des particularités de localisation et de conception, il faudrait examiner chaque installation individuellement, ce qui n'est évidemment pas possible dans le cas présent.

L'étude repose donc sur l'information qu'on a pu obtenir concernant plusieurs projets représentatifs et sur la coopération des fournisseurs. De plus, les coûts d'installation ainsi que ceux d'exploitation et d'entretien sont estimes au besoin.

Dans certains cas, surtout lorsqu'il s'agit d'appareils à rendement moins élevé, certaines technologies ERP existent, mais il se peut que leur exploitation commerciale n'ait pas fait l'objet d'un grand nombre d'essais.

Les sections suivantes décrivent les détails techniques des divers systèmes ERP, expliquent comment s'est faite l'estimation des coûts, indiquent les coûts dégagés pour chaque modèle particulier des technologies ERP, et présentent les analyses économiques préliminaires permettant d'évaluer leur impact sur la rentabilité des systèmes énergétiques.

Les annexes contiennent la liste des fournisseurs d'équipement qui ont été contactés, avec une indication des résponses reçues concernant des technologies ERP particulières. Des exemplaires de

la lettre et des spécifications concernant l'équipement qui ont été envoyés sont aussi inclus.

PART 1

INTRODUCTION

1.1 BACKGROUND

This study has been carried out under the Bioenergy Development Program, Renewable Energy Branch of Energy, Mines and Resources. The objective of the study is to quantify the impact of new and improved particulate abatement equipment (PAE) on the economics of existing and new wood waste combustion systems. The results will be used by EM&R in its efforts to increase the utilization of solid wood waste, considering both economics and the environment.

1.2 INTRODUCTION

The production of useful energy from solid wood waste, although not a large contributor to the overall energy demand at this time, has the potential for making a significant impact in areas of the country which are traditionally high energy cost areas with abundant supplies of wood waste.

However, the remoteness of the potential and existing wood waste conversion facilities do not exempt them from providing acceptable emission levels and project economics must reflect the costs of attaining these acceptable levels.

The wide range of types of combustors and pollution abatement technology currently available and being used mean that a comprehensive evaluation could require a significantly greater level of effort than was contemplated for this study. An example of the complexities involved is found in the area of retrofitting abatement equipment to existing combustion facilities. Site and design specifics would require an installation by installation approach which clearly is not possible in this case.

The study thus relies on available information from several representative projects and the cooperation of suppliers. In addition, estimates of installation costs as well as operation and maintenance costs are made where circumstances require.

Also in some cases, mainly the smaller output units, certain abatement equipment technologies are available, but may not have significant operating experience in commercial operations.

The sections which follow outline the technical details of the various PAE systems, establish the basis for cost estimates, outline the costs developed for each size range of each PAE technology and perform the preliminary economic analysis to assess the impact on the energy system economics.

Appendices contain the listing of equipment suppliers who were contacted with an indication of the particular PAE replies received. Also included is a copy of the letter and equipment specifications which were sent out.

PART 2

TECHNOLOGY REVIEW

2.1 INTRODUCTION

2.1.1 Types of Particulate Abatement Equipment [PAE]

The following four generic types of particulate abatement equipment [PAE] are marketed by suppliers for application to abatement of particulate emissions from wood fired steam generators:

- Multicyclones [MC]
- Wet Scrubbers [SCR]
- Fabric Filter Baghouses [FF]
- Electrostatic Precipitators [ESP]

An installation may use only one of these types of PAE or more than one in a series combination setup.

2.1.2 Costs for PAE Equipment

This study has developed PAE cost estimates for four selected steam plant ratings within the range 5-450 GJ/h in steam enthalpy, as shown in Table 2-1.

TABLE 2-1: PLANT RATINGS SELECTED WITHIN THE SPECIFIED RANGE OF CAPACITIES

Specified Range of Steam Plant Capacities GJ/h in Steam Enthalpy			Selected Plant Size Within Specified Range GJ/h in Steam Enthalpy
5	to	20	15
20	to	60	40
60	to	150	100
150	to	450	300

2.2 EMISSION GUIDELINES

For the purposes of this study, federal guidelines embodied in the Clean Air Act (Thermal Power Generating Emissions: National Guidelines for New Stationary Sources, Oct. 1981) have been used for specifying equipment performance in order to develop PAE cost estimates on a uniform basis.

Most provincial regulations are currently under review, and it is possible that those which are eventually legislated may be more stringent than the existing

federal guidelines of 43 ng/J (0.1 lb/10^6 Btu) for particulate emissions at source.

The Ontario situation is discussed here as an example of the status of legislation in most provinces.

In August 1990, the Government of Ontario issued a Draft Regulation under the Clean Air Program, entitled "Stopping Air Pollution at its Source". This document does not yet prescribe emission limits for pollutants from the sources listed in the Source Classification Codes [SCC] which are included in Appendix 7-1 of the Draft Regulation. Meanwhile, the draft Regulation states its intentions as follows:

QUOTATION

In the final draft of the regulation, this appendix will include a list of emission limits obtained by the Ministry from other jurisdictions. To date, copies of the legislation from the federal level in 24 countries, and the state and province level in the United States and Canada has been obtained and is in the process of being analyzed.

In progress reports, the contractor hired to obtain the information now under review noted that there is a reasonable breadth of data on "criteria pollutants" (sulphur dioxide, nitrogen oxides, carbon monoxide, lead, volatile organic compounds, suspended particulate matter, ozone and reduced sulphur compounds). However, regulated levels for non-criteria pollutants are sparse. Many jurisdictions have taken a case-by-case approach. In many of the United States, regulators have modified the LAER and BACT requirements to derive a "T-BACT" (T standing for "toxics"). The Bush, Senate and Congressional proposals for amendments to the U.S. Clean Air Act include similar approaches, termed MACT (for "Maximum Achievable Control Technology") in President Bush's original proposal.

Additional information is potentially available at the air quality management district level in the U.S., and at the regional/provincial/territorial level in other of the 24 countries surveyed to date. Along with reviews of the case-specific evaluations being performed in the U.S., such an investigation will yield additional emission standards which may be implemented without requiring applicants to perform Technology Reviews and Ministry staff to review and approve them. Where chemical-specific control performance data is lacking currently, emission limits may be set on the basis of broad pollutant categories (e.g., particulate matter or volatile organic compounds) with conditions requiring the owner or operator of a source to provide performance test results sufficient to establish chemical-specific limits by a specified deadline.

It is proposed that, as emission standards are to be set on a source-specific basis where the source is defined in a narrow sense (as a discrete portion of a facility or establishment - see glossary) the U.S. system of Source Classification Codes (SCC) be used in assigning emission standards. A copy of the listing of assigned SCCs is appended. The final schedule of emission limits would state the SCC and description of the process controlled, the contaminants emitted after control, and the emission limits for each with units of either:

- kg pollutant emitted per Mg product output,
- kg pollutant emitted per Mg raw material input, or
- kg pollutant emitted per GJ heat input."

END QUOTATION

Pending legislation, the Ontario Ministry of Environment temporarily limits new steam generators fired with treated or contaminated (viz. salt laden) wood to particulate emissions of 20 mg/Rm^3 (0.0087 gr/dscf), where R = dry/25°C/101.3 kPa/11%0_2, and those fired with virgin wood to 90 mg/Rm^3. [See "Interim Design and Review Guidelines for Wood Fired Combustors" August 1990, Approvals Branch, Ontario Ministry of Environment, principal author Ms. Anne Maria-Pennanen, Air Specialist Approval Branch, courtesy of Mr. Ken Smith, Supervisor, Source Assessment and Technology Unit - 416/326-1651]. The emission limit of 20 mg/Rm^3 is, in most cases, lower than the emission limit of 43 ng/J contained in the federal guidelines used by this study. Since provincial policies are under review, and the emission limits they currently use are both non-uniform and subject to change, it was not considered possible that the basis of this report could be changed to reflect a variety of transient situations.

2.3 EQUIPMENT REVIEW

Particulate abatement equipment [PAE] is divided generically into the four types listed in 2.1.1 above. There are several sub-types and hybrids within each generic type, but it was not appropriate to address them within the scope of this work. A brief description of each generic type is given below. Those seeking more detailed performance descriptions are referred to a report of ENFOR PROJECT C-258 produced in December 1983 entitled "A Comparative Assessment of Forest Biomass Conversion to Energy Forms - Volume VI". The information in Table 2-2 is adapted from that report and summarizes the comparative performance of the four types of PAE.

TABLE 2-2: SUMMARY OF GENERAL CAPABILITIES OF PARTICULATE ABATEMENT EQUIPMENT

	Multi-Cyclones	Fabric Filters	Electrostatic Precipitators	Wet Scrubbers
Particulate Moisture	dry	dry	dry/wet	dry/wet
Dry or Wet Operation	dry	dry	dry/wet	wet
Minimum Size Collected (μm)	5-25	0.1-1.0	0.01	0.5-10
Collection Efficiency (%)	75-90	95-99+	>99	75-99
Temperature Limit (°C)	600	260-900	300-600	>600
Relative Equipment Cost	low	moderate -high	high	low-moderate
Relative Operating Cost	low	moderate -high	low	high
Space Required	small	moderate -bulky	bulky	small-moderate

2.3.1 Multicyclone (MC)

Single cyclones and multicyclones are mechanical separators which use centrifugal forces to separate and remove particulates which have been entrained in flue gas streams emerging from boilers. The gas stream entering the cylinder of a cyclone is forced into a high speed vortex which throws the entrained particles away from its axis so that they impinge upon, and are collected by, the wall of the cylinder, while the gas exits the cylinder through a central passage. Since centrifugal force = mv^2/r, where 'm' is particle mass, 'v' is particle velocity and 'r' is radius of particle path, it is clear that efficiency of collection will be directly proportional to 'm' and 'v^2' and inversely proportional to 'r'. For these reasons, cyclone separators have the following performance characteristics as itemized in Table 2-3:

- They are more efficient for heavier (>10 μm) than for lighter particles. The latter escape collection by remaining entrained in the gas stream.

- They are more efficient when the gas velocity in the cyclone is high. This requires parallel multicyclone banks to optimize pressure drop and I.D. fan power.

- They are more efficient when the radius of the cyclone cylinder is small. This accounts for the preference for using several small diameter cyclones (multicyclone) in place of one large diameter (single) cyclone.

Multicyclones are the least expensive of the four generic PAE types discussed in this report.

The performance characteristics of cyclones are shown in Table 2-3.

TABLE 2-3: CYCLONE COLLECTOR CHARACTERISTICS

	Single Large Diameter Cyclones	Multiple Small-Diameter Cyclones
Dust Inlet Loading (g/m3)	moderate >2.3	moderate >2.3
Particle Size Removed (μm)	>25	>10
Collection Efficiency (%)	<85	<95
Pressure Drop (Pa)	125-750	500-1,500
Gas Velocity (m/s)	10-20	10-20
Maximum Gas Flow (m3/s)	25	100

2.3.2 Wet Scrubbers (SCR)

Wet scrubbers operate on the principle of contact between the incoming particle-laden flue gases and the droplets of a liquid spray. The liquid spray permits the gas to flow onward but wets and captures the entrained particles so that they are forced to separate from the gas stream. Wet scrubbers operate

on a variety of mechanical principles for bringing about an efficient contact between the liquid spray and the particles in the gas stream such as, venturi, impingement, cyclonic or gravity spray, or on selected combinations of these mechanical principles. The characteristics of a few sub-types of wet scrubbers are given in Table 2-4.

TABLE 2-4: SUMMARY OF THE OPERATING CHARACTERISTICS OF WET SCRUBBERS

	Spray Tower	Cyclonic Spray Tower	Impinge-ment	Venturi
Maximum Gas Temperature (°C)	370	370	370	370
Maximum Gas Flowrate (m^3/s)	>100	>100	100	100
Dusting Loading (g/m^3)	>1.0	>1.0	>1.0	>0.1
Minimum Particle Size (μm)	10	2	1	0.5
Collection Efficiency (%)	70	96	98	99
Liquid Requirements (L/m^3 gas flow)	0.2-0.8	0.2	0.1-0.2	0.25-0.6
Pressure Drop (kPa)	0.25-0.50	0.5-1.5	0.25-1.0	1.5-18.0
Equipment Cost	low-moderate	low-moderate	moderate	moderate
Operating Cost	moderate	high	high	high

2.3.3 Fabric Filter Baghouses [FF]

Fabric filters operate on the principle of sieving material through a mesh, so that entrained particles larger than the openings in the mesh are retained and clean gas is permitted to pass. When the particles retained on the upstream side of a filter gradually accumulate, they form a filter-cake which itself, up to a point, augments filtration. After a certain degree of cake formation, gas flow is obstructed by the cake and pressure drop across the filter increases. When differential pressure sensors indicate that the pressure drop has reached a set level, gas flow to that section of the baghouse is cut off, and the fabric filter is cleaned by reverse/pulsed compressed air and/or mechanical agitation so that the cake drops into collection hoppers for discharge to the ash removal system. Fabric filters are not used to collect corrosive, wet or sticky particles nor condensibles such as tars and oils which would impair collection efficiencies of filter materials. Tables 2-5 and 2-6 list the main performance characteristics of fabric filters. Selection of fabric filter material is an important factor in optimization for the PAE, along with the gas-to-cloth ratio which is expressed in meters per second or feet per minute [i.e. gas flow in $m^3/s \div$ cloth area in m^2 = cloth-to-gas ratio in m/s]. The lower the ratio, the more efficient the filter, but the greater the cost. Bag life is typically two years and replacement is staggered, so that a few bags are replaced each month. Typical gas velocities through baghouses are less than 0.1 m/s which accounts for the large physical size and high space requirement for this type of PAE.

TABLE 2-5. CHARACTERISTICS OF VARIOUS FILTER FABRICS

Generic Name	Trade Name	Max. Continuous Temp. (°C)	Max. Short-Time Temp. (°C)	Tensile Strength	Supports Combustion	Resistance to				
						Abrasion	Alkalies	Acids	Agents	Biological Attack
Cotton	—	80	95	good	yes	average	good	poor	fair	poor, unless treated
Wool	—	95	110	poor	no	average	poor	good	fair	poor, unless treated
Polyamid	Nylon	95	120	excellent	yes	excellent	good	poor	fair	no effect
Polypropylene	Herculon	95	105	excellent	yes	good	excellent	excellent	good	excellent
Polyester	Dacron	130	150	excellent	yes	excellent	fair	fair	good	no effect
Acrylic Copolymer	Orlon	120	120	average	no	average	fair	good	good	good
Homopolymer Acrylic	Dralon T	140	140	average	yes	average	fair	excellent	good	good
Aramid	Nomex	205	230	very good	no	very good	good	fair	poor	no effect
Flurocarbon	Teflon	260	85	average	no	below average	excellent	excellent	excellent	no effect
Glass	Fibreglass	260	285	excellent	no	poor	fair	very good	excellent	no effect
Metal Alloy	Bekinox	450	510	excellent	no	very good	very good	very good	very good	no effect
Metal Alloy	Hastelloy	900	900	excellent	no	very good	very good	very good	very good	no effect
Metal Alloy	Incoloy	600	700	excellent	no	very good	very good	very good	very good	no effect

TABLE 2-6: SUMMARY OF OPERATING CHARACTERISTICS FOR FABRIC FILTERS

	Fabric Filter
Maximum Gas Temperature (°C)	260 - nonmetallic 900 - metallic
Minimum Particle Size (m)	0.1
Collection Efficiency (%)	99
Dusting Loading (g/m^3)	> 2.3
Maximum Gas Flowrate (m^3/s)	100
Equipment Cost	moderate
Operating Cost	moderate
Space Required	large

2.3.4 Electrostatic Precipitators [ESP]

Electrostatic precipitation operates on the principle of electrically charging the particles in the flue gas stream as it flows between high direct current voltage electrodes. The charged particles are deflected onto collecting electrodes from where they are dislodged by mechanical agitation (rapping) and fall into removal equipment for discharge to the ash disposal system.

It is important that the gas flow through the ESP be uniform and non-turbulent, and that temperatures above dew point be maintained in the ESP in order to prevent corrosion. Electrical resistivity of the particles to be collected determines the physical configuration and voltage of the electrical system. Potential for sparking creates a fire hazard, particularly if carbonaceous or combustible materials are entrained in the gas stream.

The principal performance characteristics of ESP are listed in Table 2-7.

TABLE 2-7: SUMMARY OF OPERATING CHARACTERISTICS OF ELECTROSTATIC PRECIPITATORS

Maximum Gas Temperature (°C)	600
Minimum Particle Size (m)	0.01
Collection Efficiency (%)	> 99
Dusting Loading (g/m^3)	> 0.2
Maximum Gas Flowrate (m^3/s)	> 1,000
Equipment Cost	high
Operating Cost	low to moderate
Space Required	high
Power Consumption (kW per m^3/s of gas flow)	0.2 - 0.65
Pressure Drop (kPa)	0.05 - 0.25

2.3.5 Greenfield and Retrofit - PAE Installations

Particulate abatement equipment [PAE] for wood fired combustors is generally specified to meet the following 'rating' and 'performance' criteria:

- The 'rating' of PAE must be based on the quantity (m^3/s) and quality (temperature, moisture content, particulates loading, etc.) of the flue gases to be handled by PAE. These constitute the input conditions to be satisfied by design.

- The 'performance' of PAE must be such that the output gases from PAE meet the limitation on emission of particulates prescribed by regulatory authorities in the Certificate of Approval [C of A] which is granted to the facility.

There is a multiplicity of requirements, within and besides these 'rating' and 'performance' criteria, which the PAE must be designed to satisfy; they are all site and system-specific and are not susceptible of detailed discussion within the

generalized framework of this study. They relate to specifics such as requirements for the following:

- Interconnection with upstream and downstream equipment (example: avoidance of turbulent conditions at PAE intake).

- Draft system design, so that the pressure drop of the PAE and the fan power requirements are taken into account for the whole operating range of both existing and retrofit equipment.

- Foundations and support structures (non-interference with those in place).

- Connection to, and adequacy of, utilities such as the following:

  - ash discharge and collection system

  - water requirements for scrubbers and for quenching of ash

  - electrical power for PAE drives, and for ESP fields

  - steam or electrical heating power for maintaining above dew-point temperatures for corrosion prevention (particularly under winter conditions).

Greenfield conditions are always easier to design for, particularly with regard to PAE layout, foundations, support structures, flue gas ducting and by-passes.

Retrofit installations are often difficult, except in cases where the original designers foresaw, and designed for, prospective changes in 'rating' or 'performance' requirements. Such foresight is unusual but not impossible. Some recent wood fired boiler facilities in Ontario have initially installed multicyclones but, in anticipation of more stringent emission regulations, have so designed their layout that scrubbers can be added at a later date. Apart from providing for equipment layout and construction access, they have also designed their draft systems for extra fan power which will be required when the scrubber is added and the system pressure drop increases, as well as for all the utilities (water, power, compressed air, etc.) which may be required for performance enhancement to meet new regulations.

Where such foresight has not been applied, retrofit problems can range from the difficult to the impossible, and each retrofit situation has to be reviewed as a special case in relation to its site and system-specific information.

2.4 PERFORMANCE SPECIFICATIONS AND ENQUIRIES TO SUPPLIERS

The following steps were taken with the object of obtaining uniform pricing data from PAE suppliers:

a) A list of suppliers was compiled, and telephone contact was established with an appropriate representative in each company [Appendix-1].

b) A system diagram [Appendix-2] was prepared indicating the following:

- Boiler and immediate auxiliaries showing reinjection from economizer and air heater systems.
- Primary air pollution control [APC] unit - in all cases a multicyclone.
- Secondary air pollution control [APC] unit - choice of scrubber, fabric filter baghouse or electrostatic precipitator.

c) Performance specifications were prepared for primary and secondary APC units [Appendix-2]. A considerable mass of information from industrial, laboratory and demonstration testing was reviewed in order to arrive at acceptable input-output conditions which could be used for setting performance criteria against which numerous PAE suppliers could provide budgeting prices on a non-site specific and non-system specific and yet uniform basis. The selected performance specifications were discussed with suppliers to establish that they were acceptable in relation to their standard equipment performance, so that pricing would reflect offers for standard rather than customized equipment. It was found that the specifications prepared were uniformly acceptable. Some scrubber manufacturers commented that their equipment did not need upstream multicyclones, since their equipment could handle the full concentration of particulates in flue gases from the boiler (up to 12,000 mg/m^3), thus acting as combined primary and secondary APC systems. However, since this is a non-site and non-system specific evaluation covering a limited number of variables, it was decided to maintain the technical system distinction between primary and secondary APC systems.

d) A covering letter and supplier response sheets were prepared to facilitate uniformity in supplier data [Appendix-2].

Enquiries prepared in accordance with these four steps were sent to the PAE suppliers who are listed in Appendix-1. An 'x' is marked in the appropriate column to identify the suppliers who responded with prices for PAE equipment.

PART 3

COST ESTIMATES

3.1 BASIS OF COST ESTIMATES

Capital costs have been developed for four (4) generic types of particulate abatement equipment [PAE] and for four (4) cases for each PAE type.

Capital costs for PAE are based on responses received from suppliers to enquiries which were directed to them. A table in Appendix-1 contains a list of the suppliers to whom enquiries were sent. Crosses are marked on that table to identify suppliers who responded and the generic PAE types which they offer to supply.

Energy system [ES] capital costs were developed for four (4) plant size CASES, with and without PAE. Energy system costs were developed using Monenco's in-house data.

The four plant size CASES for which costs were estimated are as follows:

CASE-1	15 GJ/h in steam enthalpy
CASE-2	40 GJ/h in steam enthalpy
CASE-3	100 GJ/h in steam enthalpy
CASE-4	300 GJ/h in steam enthalpy

The four generic types of PAE for which costs were estimated are as follows:

- Multicyclones [MC]
- Wet Scrubbers [SCR]
- Fabric Filter Baghouses [FF]
- Electrostatic Precipitators [ESP]

Operating and maintenance (O&M) costs for PAE and ES were estimated using Monenco's in-house data.

All costs are in 1990 Canadian dollars.

Utilities were estimated on the following basis:

Electrical energy:	\$50/MWh
Water:	\$ 0.8/m^3

3.2 PAE COSTS

Cost information received from suppliers was reviewed and compared with in-house and published information. Where necessary, suppliers were requested to clarify their information or to submit revised prices. Comparison of supplier data was carried out for each CASE within each PAE type. Apart from a few

obvious discrepancies which were set aside, it was found that supplier prices were reasonably consistent.

Using finally accepted supplier information the installed capital costs for the four (4) generic types of PAE were plotted as shown in Figure 3-1. The characteristics were then used for determination of capital costs of the selected four CASES of plant ratings (15, 40, 100, 300 GJ/h) for each of the four generic PAE types (MC, SCR, FF, ESP).

3.3 ENERGY SYSTEM COSTS

Capital and O&M costs for energy systems [ES] were developed using Monenco's in-house data and recent supplier information.

Cost information was developed for ES with and without PAE. The scope for ES is defined as follows for each of the four CASES:

- Boiler & Auxiliaries

- Main Steam Generator
  - a- Feeder and Drives
  - b- Fuel Firing System
  - c- Boiler Pressure Parts and Buckstays
  - d- Air Preheaters
  - e- Ducts & Dampers
  - f- Insulation
  - g- Casing
  - h- Valves & Fittings
  - i- Soot Blowers

- Boiler Draft System
  - a- FD Fans & Drives
  - b- ID Fans & Drives
  - c- PA Fans & Drives
  - d- Seal Air Fans and Drives
  - e- GR Fans & Drives

- Fuel Handling
  - a- Fuel Receiving
  - b- Stacking & Reclaiming
  - c- Fuel Preparation
  - d- Transfer to Unit Silos
  - e- Electrical

- Ignitor Fuel System
  - a- NO_2 oil or Natural Gas System

- Ash Handling Plant
  - a- Furnace Bottom Ash & Pulverizer Rejects Removal
  - b- Fly Ash Dust Removal
  - c- Plant Ash Handling Systems
  - d- Electrical

- HP Piping, Boiler Drains, Blowdown & Venting
  - a- Main Steam Piping
  - b- Hot Reheat Steam Piping
  - c- Cold Reheat Steam Piping
  - d- Auxiliary Steam System
  - e- Boiler Blowdown, Vents, Valves, Fittings
  - f- Blowdown Tank & Vent Stack
  - g- Chemical Cleaning

3.4 COST AND PERFORMANCE DATA

Table 3-1 presents all the cost and performance information which has been developed.

3.4.1 Energy System [ES] Performance and Costs

Energy system performance for the four CASES is presented in items 1 through 11. It will be seen that performance, and hence the thermal efficiency and fuel consumption, is based on assumed steam conditions which are considered reasonably typical for each of the four sizes of wood fired steam plants on a non-site, non-system specific basis. Again, on a typical basis, it was assumed that feed water heat would uniformly constitute 18% of steam enthalpy. Taking this into account, the fuel feed rate in GJ/h and green wood fuel input in Mg/h was computed for each CASE. Annual availability of 85% was assumed for each CASE under base load (MCR) conditions, so that annual fuel consumption was based on 85% annual capacity factor (ACF). The annual fuel consumption for each ES was developed assuming a cost of $4.66/GJ for chipped, green, 50% moisture content wood fuel delivered to the ES. Wood fuel was uniformly assumed to have a higher heating value of 19.788 GJ/od Mg (8,500 Btu/od lb).

The direct installed costs of ES were developed as discussed in Part 3.1 above. Indirect costs have been uniformly assumed at 30% of directs. They include the following, excluding cost of land:

- Construction Buildings and Structures.
- Construction Costs.
- Engineering and Regulatory Permitting.
- Owner's Costs of Project and Construction Management.

- Commissioning Expenses.

Operating and maintenance costs are based on typical industry, non-utility norms.

3.4.2 PAE Performance and Costs

PAE systems for the four CASES were uniformly assumed to consist of Primary and Secondary systems, performing in series to meet federal guidelines of 43 ng/J for particulate emissions, as discussed in Part 2.2 of this report. Part 2.2 also discusses why this criterion of performance was selected. ES-PAE configurations for this evaluation are shown in Appendix-2, along with details of flue gas quantities, qualities and particulate loadings for both Primary and Secondary PAE systems.

Direct installed costs have been developed as discussed above in Parts 3.1 and 3.2.

Total installed costs are obtained, as for ES systems, by adding 30% indirects to the direct installed costs.

Annual operating and maintenance costs for PAE are developed using industry norms. The variable O&M costs for utilities such as power, water, compressed air, are based on the consumption of utilities for various types of PAE.

Figure 3-1

DIRECT INSTALLED COST OF PAE FOR WOOD FIRED COMBUSTORS

1. Multicyclones (MC)
2. Wet Scrubbers (SCR)
3. Fabric Filter Baghouses (FF)
4. Electrostatic Precipitators (ESP)

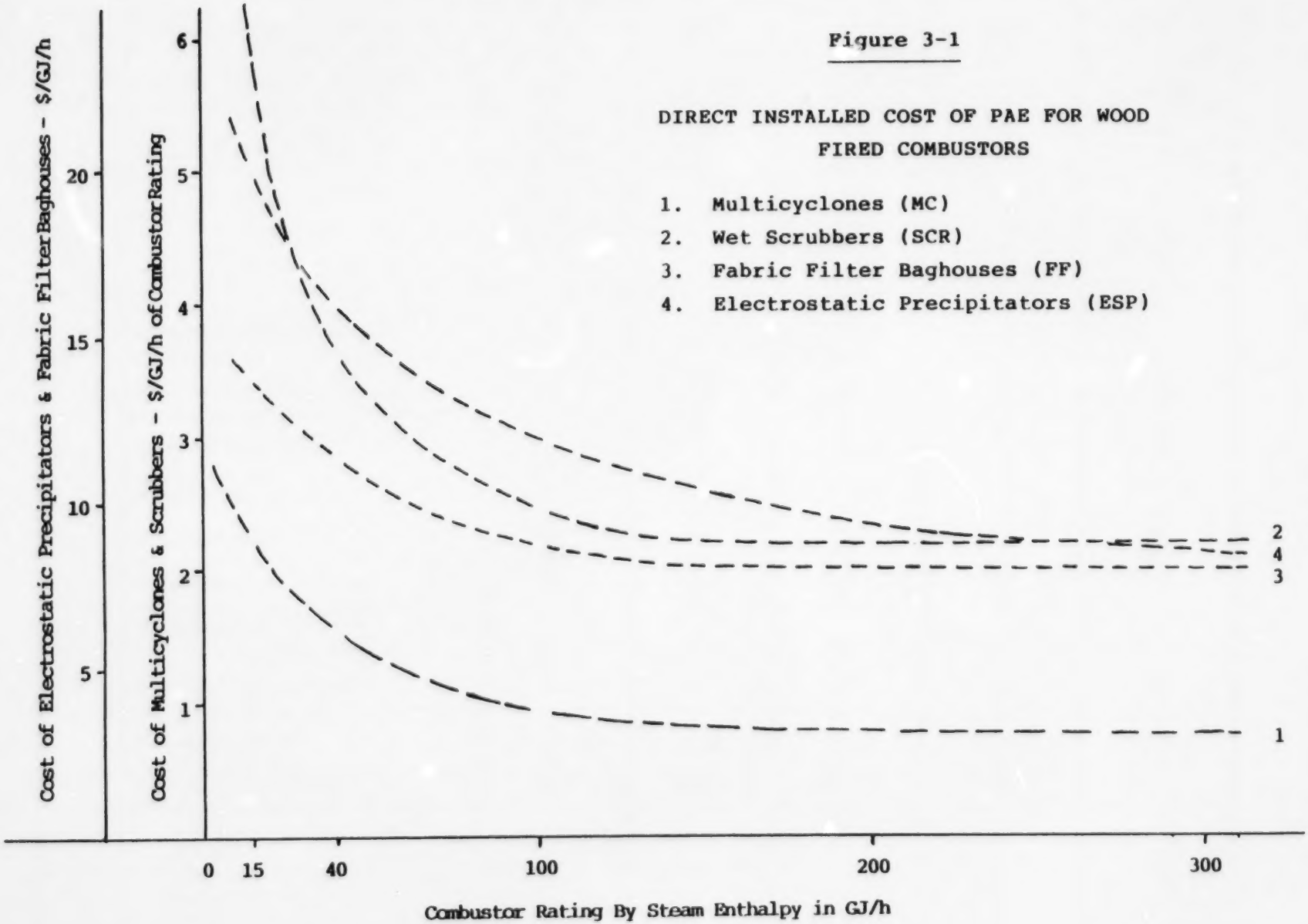

TABLE 3-1: DATA SUMMARY
(All Costs are in 1990 Canadian Dollars)

No.	Item	Unit	Case 1	Case 2	Case 3	Case 4
1	Combustor size range	GJ/h Steam	5-20	20-60	60-150	150-450
2	Size selected for evaluation	GJ/h Steam	15	40	100	300
3	Assumed steam conditions					
	3.1 Pressure	kPa	1827	4309	4309	6378
		psia	265	625	625	925
	3.2 Temperature	°C	208	400	400	482
		°F	425	750	750	900
	3.3 Enthalpy	GJ/Mg	2.824	3.21	3.21	3.38
		Btu/lb	1213	1379	1379	1451
	3.4 Steam Flow	Mg/h	5.3	12.46	31.15	88.8
		lb/h	11,684	27,472	68,680	195,790
4	Assumed boiler efficiency	%	60	65	65	65
5	Heat ratio: feed/steam		0.18	0.18	0.18	0.18
6	Assumed heat ratio: fuel/steam		1.3	1.2	1.2	1.2
7	Fuel heat input	GJ/h	19.5	48	120	360
8	HHV of green fuel @50% m.c.	GJ/Mg	9.894	9.894	9.894	9.894
		Btu/lb	4,250	4,250	4,250	4,250
9	Fuel feed rate	Mg/h	1.97	4.85	12.13	36.39
10	Availability @85% approx.	h/a	7500	7500	7500	7500

TABLE 3-1 (Cont'd)

No.	Item	Unit	Case 1	Case 2	Case 3	Case 4
11	Annual green fuel consumption	10^3 Mg/a 10^3 GJ/a	14.8 146	36.4 360	91 900	273 2,700
12	Cost of chipped wood fuel delivered to plant	$/GJ	4.66	4.66	4.66	4.66
13	Annual fuel cost	10^3 $/a	680	1,678	4,194	12,582
14	Installed direct capital cost of Energy System [E.S.] without P.A.E. (Graph C)	10^3 $/a	1,665	4,120	8,600	18,300
15	Installed capital cost of E.S. without P.A.E. adding 30% for indirects.	10^3 $	2,165	5,356	11,180	23,790
16.	Installed capital cost of P.A.E. systems (direct costs only)					
	16.1 Multicyclones (MC)	10^3 $	34	62	95	225
	16.2 Scrubbers (SCR)[*]	"	90	148	250	660
	16.3 FF/Baghouses (FF)[*]	"	206	460	880	2400
	16.4 Electrostatic Precipitators (ESP)[*]	"	293	640	1,200	2,500
	16.5 MC + SCR[*]	"	124	210	345	885
	16.6 MC + FF[*]	"	240	522	975	2,625
	16.7 MC + ESP[*]	"	327	702	1,295	2,725
	16.8 SCR + FF[**]	"	296	608	1,130	3,060
	16.9 SCR + ESP[**]	"	383	788	1,450	3,160
	16.10 MC + SCR + FF[**]	"	330	670	1,225	3,285
	16.11 MC + SCR + ESP[**]	"	417	850	1,545	3,385
	[*] These combinations will meet meet federal guidelines of 43 mg/J.					
	[**] These combinations may surpass existing federal guidelines of 43 ng/J.					

TABLE 3-1 (Cont'd)

No.	Item	Unit	Case 1	Case 2	Case 3	Case 4
17	Total installed cost of selected P.A.E. to comply with guidelines of 43 ng/J particulate emissions (per Item 16.5 above plus 30% for indirects)	10^3 $	161	273	500	1,150
18	Ratio: Cost of P.A.E./Cost of E.S. without P.A.E. (Items 17/15)	-	0.07	0.05	0.04	0.05
19	Total installed capital cost of E.S. plus selected P.A.E. [Items 15 + 17].	10^3 $	2,326	5,629	11,680	24,940
20	Operating staff for S.E. + P.A.E. (3-shift basis)	#	8	9	11	12
21	Fixed annual operating cost at average $40,000/a/person	10^3 $	320	360	440	480
22	Fixed annual operating cost as percentage of total capital costs in Item 19 (the same percentage is applicable to Items 15 and 17).	%	23	11	6.5	3.5
23	Variable annual O&M for selected P.A.E. of Item 17 including utilities (electrical power and water) as a percentage of capital cost in Item 17.	%	23	34	53	56
24	Variable annual O&M of E.S. without P.A.E. (as a percentage of Item 15) including utilities (electrical power and water)	%	11	10	8	8
25	Annual fuel cost as a percentage of total capital cost of Item 19.	%	49	51	63	85
26	Annual production of wet ash [@50% M.C.] assumed 2.5% of weight of green fuel consumption	Mg/a	370	900	2,300	6,800

TABLE 3-1 (Cont'd)

No.	Item	Unit	Case 1	Case 2	Case 3	Case 4
27	Annual cost of ash disposal at $80/Mg including transportation [@ assumed bulk density of 720 kg/m^3 = 45 lb/ft^3]	10^3/a	30	72	184	544
28	Variable annual O&M costs for P.A.E. systems including utilities [electrical power @ $50/MWh and water @ $0.80/m^3 or $3.00/USg]					
	28.1 Multicyclones [MC] as % of 1.3 x Item 16.1	%	6	6	4	4
		10^3/a	2.8	4.6	5.6	11.4
	28.2 Scrubbers [SCR] as % of 1.3 x Item 16.2	%	18	26	42	42
		10^3/a	21.6	50	130	346
	28.3 FF/Baghouses [FF] as % of 1.3 x Item 16.3	%	6	6	5.5	5.5
		10^3/a	16	36	63	170
	28.4 Electrostatic Precipitators [ESP] as % of 1.3 x Item 16.4	%	5	5	4	4.5
		10^3	15	32.5	68	140
29	Variable annual O&M costs for P.A.E. systems without utilities [to be taken as percentages of 1.3 x Items 16.1, 16.2, 16.3, 16.4]	%	3	3	2	2

PART 4

COST ANALYSIS

4.1 INTRODUCTION

The cost analysis carried out for this study is based on the cost estimates presented in Part 3 for the four different sizes of energy facilities and the various combinations of abatement equipment (PAE). The approach used is to set the energy system up without the pollution abatement facility, as a steam producer only. A hypothetical steam selling price is then determined which will give a 25% return on cash flow, before tax, over a twenty year period. Twenty years represents the estimated economic life of this type of installation.

With the revenue stream thus determined, the additional costs of the pollution abatement equipment, both capital and operating, are applied to the energy system cash flows and the impact on the average annual return is calculated.

In the analysis, income taxes and the method of financing the capital expenditures are not considered, since this is merely a screening exercise to determine the relative economics of various pollution abatement measures. The sections below outline the assumptions made and other inputs to the cost comparison spreadsheet.

The capital and operating cost estimates from Part 3 are re-stated in Tables 4-1 and 4-2 for the energy systems and PAE.

4.2 ECONOMIC PARAMETERS

In order to create the spreadsheet model and project cash flows over the life of the facility, it is necessary to make some assumptions regarding escalation rates, interest rates and other key variables. These assumptions then form the basis of the analysis and remain unchanged for each alternative abatement system.

Since this analysis is a comparison of costs of mutually exclusive systems, and net present values are used as the measure of comparison, the costs have been projected in constant (1990) dollars. This means that only in cases where costs are forecast to change at rates significantly different from the general rates of inflation will there be any escalation factors applied. The results of this "real" cost analysis are no different from those in which general escalation rates are applied to all costs since the indicated returns will be affected similarly if the rates have been used consistently.

One of the assumptions made is that the internal rate of return over the twenty year study period should be targeted at 25%, before taxes and financing charges. This is the return on the base energy system for all sizes analysed. Since the method of analysing the economics of the pollution abatement equipment is based on measuring the impact on the IRR of the base energy system without PAE, the actual IRR value chosen is somewhat irrelevant. The

Table 4-1
Pollution Abatement Equipment
Capital Cost Summary

(1990 $000)

	CASE 1	CASE 2	CASE 3	CASE 4
Energy System only (Table 3-1)	2165	5356	11180	23790
Abatement Systems				
MC + SCR	161	273	500	1150
SCR	117	192	325	858
FF	268	598	1144	3120
ESP	381	832	1560	3250
MC + FF	312	679	1268	3413
MC + ESP	425	913	1684	3543
SCR + FF	385	790	1469	3978
SCR + ESP	498	1024	1885	4108

Table 4-2
Pollution Abatement Equipment
O & M Cost Summary

% of Capital Cost
(except as noted)

		CASE 1	CASE 2	CASE 3	CASE 4
Energy System only	-Fixed - %	23.0	11.0	6.5	3.5
	-Fuel $000	680	1678	4194	12582
	-Ash Disposal $000	30	72	184	544
	-Variable - %	11.0	10.0	8.0	6.0
Variable Only - %					
MC + SCR (per Item #28)		24.0	32.0	46.0	46.0
SCR		18.0	26.0	42.0	42.0
FF		6.0	6.0	5.5	5.0
ESP		5.0	5.0	4.0	4.0
MC + FF		12.0	12.0	9.5	9.0
MC + ESP		11.0	11.0	8.0	8.0
SCR + FF		24.0	32.0	47.5	45.0
SCR + ESP		23.0	31.0	46.0	46.0

level of 25%, however, was judged appropriate for this preliminary stage of the investigation, given the degree of uncertainty involved in the other parameters.

The other parameters used in the analysis are summarised in Table 4-3.

Table 4-3
Economic Parameters

Facility Economic Life	20 Years
Annual Operating Period	7500 Hours
Fuel Cost	4.66 $/GJ
Average Annual Manpower Cost	$40,000/Year
Cost of Ash Disposal	$80/Mg

4.3 ANALYSIS

The spreadsheet developed for this analysis assumes constant steam output and heat rates from year 1 through year 20. The steam output from the energy system without PAE is priced at a level which will give an IRR of 25% over the 20 year period. This establishes the revenue stream and net cash flow against which the additional investment and operating costs of the PAE must be applied.

With the various alternative PAE systems providing levels of particulate reductions sufficient to meet federal guidelines, it then becomes a question of measuring the reduction in IRR for each competing system.

No attempt has been made to match the abatement capabilities of each system and, in fact, several of the alternatives have been designed to significantly improve on the federal guidelines, in order to show the impact on returns if the emission limits were to be lowered. The combinations of abatement equipment and their removal capabilities are described in Part 2.

The analysis is summarised as annual net cash flows, assuming the capital expenditures are made in year zero and full output is available throughout year 1. There are no capital additions over the 20 year life cycle, with regular and major maintenance costs assumed to be included in the annual fixed and variable maintenance charges.

For each of the four sizes of facilities, an annual revenue is determined based on the projected steam output and a selling price which will return 25% per annum on the basic energy system investment. The capital and operating costs for each of the eight pollution abatement systems are applied to this basic facility and the IRR is re-calculated for each without making adjustments to the revenue stream (since the steam output is not affected). An example of the cash flow summary for the energy system only is given in Table 4-4. The corresponding cash flow summary with a PAE system added follows in Table 4-5. The results for the complete series of eight PAE systems are tabulated for all four cases in Table 4-6.

4.4 RESULTS

The results indicate IRR reductions in the range of 3-6% for most of the PAE systems, with the exceptions being the smallest energy system (Case A) under the more complex PAE systems and the larger energy systems under the PAE combinations with the higher removal capabilities.

These reductions are not insignificant and the impact on the project feasibility would have to be tested in more detail before any firm conclusions could be reached. However, at this preliminary screening level the addition of PAE equipment to allow the energy system to meet current particulate emission guidelines does not appear to overburden the projected returns in most cases.

In fact, if financial incentives such as accelerated PAE write-off or tax credits were to be applied to the analysis (assuming they were available), the overall impact could be minimal.

TABLE 4–4
ES WITHOUT PAE

Economic Analysis
Pollution Abatement Equipment Case 1 – Graph C ($000)

		Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Revenue																	
Steam Sales	lbs/hour	7500	hours	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684
Steam Revenue	$/'000 lb.	22.75		1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Operating and Maintenance Costs																	
Fixed O&M	% of Capital	23%		498	498	498	498	498	498	498	498	498	498	498	498	498	498
Variable O&M - E.S.	% of Capital	11%		238	238	238	238	238	238	238	238	238	238	238	238	238	238
- P.A.E.	% of Capital	24%		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Cost	$ '000			680	680	680	680	680	680	680	680	680	680	680	680	680	680
Ash Disposal	$ '000			30	30	30	30	30	30	30	30	30	30	30	30	30	30
Total Operating Costs				1446	1446	1446	1446	1446	1446	1446	1446	1446	1446	1446	1446	1446	1446
Capital Expenditures :	Energy System (E.S.)		2165														
	Pol. Abate. Equip.(PAE)		0														
			2165														
Net Cash Flow			-2165	547	547	547	547	547	547	547	547	547	547	547	547	547	547
Present Value of Net Cash Flow @ 15% p.a. over 20 years		1097															
Internal Rate of Return		25.00%															

NOTE: Analysis was done for 20 years, but only 14 years are shown above.

TABLE 4-5
ES WITHOUT PAE

Economic Analysis
Pollution Abatement Equipment — Case 1 – Graph C — ($000)

				Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Revenue																		
Steam Sales	lbs/hour	7500	hours		11684	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684	11684
Steam Revenue	$/'000 lb.	22.75			1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Operating and Maintenance Costs																		
Fixed O&M	% of Capital	23%			535	535	535	535	535	535	535	535	535	535	535	535	535	535
Variable O&M - E.S.	% of Capital	11%			238	238	238	238	238	238	238	238	238	238	238	238	238	238
- P.A.E.	% of Capital	24%			39	39	39	39	39	39	39	39	39	39	39	39	39	39
Fuel Cost	$ '000				680	680	680	680	680	680	680	680	680	680	680	680	680	680
Ash Disposal	$ '000				30	30	30	30	30	30	30	30	30	30	30	30	30	30
Total Operating Costs					1522	1522	1522	1522	1522	1522	1522	1522	1522	1522	1522	1522	1522	1522
Capital Expenditures :	Energy System (E.S.)			2165														
	Pol. Abate. Equip.(PAE)			161														
				2326														
Net Cash Flow				-2326	472	472	472	472	472	472	472	472	472	472	472	472	472	472
Present Value of Net Cash Flow @ 15% p.a. over 20 years		545																
Internal Rate of Return		19.73%																

NOTE: Analysis was done for 20 years, but only 14 years are shown above.

Table 4-6
Pollution Abatement Equipment

Cost Analysis Summary

Return On Cash Flows - %

GRAPH C

	CASE 1	CASE 2	CASE 3	CASE 4
Energy System only	25.0	25.0	25.0	25.0
Steam Selling Price $/10^3 LB	$22.75	$20.55	$17.15	$14.58
Energy Systems + PAE System				
MC + SCR	19.7	21.6	21.6	21.4
SCR	21.4	22.8	22.8	22.5
FF	18.7	20.6	21.4	20.9
ESP	16.5	19.2	20.4	20.9
MC + FF	16.9	19.4	20.6	20.0
MC + ESP	14.5	17.8	19.5	20.0
SCR + FF	13.2	15.7	15.1	13.6
SCR + ESP	10.3	13.4	12.8	13.1

Notes:
1. Steam selling price is set to return 25% on 20-year cash flows for Energy System only (before tax).
2. Capital plus O & M costs for PAE systems are added, without changing steam price, to determine impact on return.
3. MC: Multi-Cyclone SCR: Scrubber FF: Fabric Filter ESP: Electrostatic Precipitator

PART 5

CONCLUSIONS

5.1 CONCLUSIONS

The PAE technologies investigated exhibit a reasonably consistent pattern in terms of economic impact on the base energy system performance, over the specified application range. The results indicate reductions in 20 year IRR's in the range of 2% to 5% for all but a few special cases.

The exceptions are in Case 1, the smallest unit size investigated, and for the compound, higher performance systems which will provide particulate reductions to levels well below current regulations.

The summary tabulation is repeated as Table 5-1 with the lower IRR cases highlighted. In most cases these reductions in economic returns still result in IRR's which could be considered acceptable, given the additional removal capabilities and other energy system alternatives in the smaller size range.

With these somewhat encouraging results at this preliminary screening stage, it appears that more detailed investigations, including site specific cost estimating and retrofit applications, are justified.

A summary of the case details and results is given in Table 5-2, following the format specified in the study Terms of Reference.

Table 5-1
Pollution Abatement Equipment

Cost Analysis Summary

Return On Cash Flows - %

GRAPH C

	CASE 1	CASE 2	CASE 3	CASE 4
Energy System only	25.0	25.0	25.0	25.0
Steam Selling Price $/10^3 LB	$22.75	$20.55	$17.15	$14.58
Energy System + PAE System				
MC + SCR	19.7	21.6	21.6	21.4
SCR	21.4	22.8	22.8	22.5
FF	18.7	20.6	21.4	20.9
ESP	16.5	19.2	20.4	20.9
MC + FF	16.9	19.4	20.6	20.0
MC + ESP	14.5	17.8	19.5	20.0
SCR + FF	13.2	15.7	15.1	13.6
SCR + ESP	10.3	13.4	12.8	13.1

Notes:
1. Steam selling price is set to return 25% on 20-year cash flows for Energy System only (before tax).
2. Capital plus O & M costs for PAE systems are added, without changing steam price, to determine impact on return.
3. MC: Multi-Cyclone SCR: Scrubber FF: Fabric Filter ESP: Electrostatic Precipitator

Table 5-2

Summary of Case Results

Type of Particulate Abatement Equipment	Suggested Range GJ/hr Actual Case GJ/hr	CASE 1 5–20 15	CASE 2 20–60 40	CASE 3 60–150 100	CASE 4 150–450 300
Multi–Cyclones	Capital Cost P.A.E. $000	44	81	124	293
	O & M $000	33	77	190	555
	Cost Ratio	0.04	0.03	0.02	0.02
	IRR% without P.A.E.	.....	.....	See Note 1	.....
	IRR% with P.A.E.	.....	.....	See Note 1	.....
	Removal Efficiency %	85–90	85–90	85–90	85–90
Scrubbers: Wet	Capital Cost P.A.E. $000	117	192	325	858
	O & M $000	52	122	314	890
	Cost Ratio	0.10	0.06	0.05	0.06
	IRR% without P.A.E.	25.0	25.0	25.0	25.0
	IRR% with P.A.E.	21.4	22.8	22.8	22.4
	Removal Efficiency %	70–99	70–99	70–99	70–99
Multi–Cyclone & Scrubber	Capital Cost P.A.E. $000	161	273	500	1,150
	O & M $000	54	127	320	901
	Cost Ratio	0.13	0.09	0.08	0.08
	IRR% without P.A.E.	25.0	25.0	25.0	25.0
	IRR% with P.A.E.	19.7	21.6	21.6	21.4
	Removal Efficiency %	>99	>99	>99	>99
Electrostatic Precipitators	Capital Cost P.A.E. $000	381	832	1,560	3,250
	O & M $000	45	105	252	684
	Cost Ratio	0.31	0.27	0.25	0.24
	IRR% without P.A.E.	25.0	25.0	25.0	25.0
	IRR% with P.A.E.	16.5	19.2	20.4	20.8
	Removal Efficiency %	>99	>99	>99	>99
Fabric Filters	Capital Cost P.A.E. $000	268	598	1,144	3,120
	O & M $000	46	108	247	714
	Cost Ratio	0.22	0.20	0.18	0.23
	IRR% without P.A.E.	25.0	25.0	25.0	25.0
	IRR% with P.A.E.	18.7	20.6	21.4	20.8
	Removal Efficiency %	99	99	99	99

Note 1: Multi Cyclones were combined with ESP for the cost analysis.

APPENDIX 1

TABLE 1: SUPPLIERS OF PARTICULATE REMOVAL EQUIPMENT FOR SELECTED GENERIC TECHNOLOGIES

NOTE: Enquiries were sent to all listed suppliers.
The check mark (x) indicates responses received.

#	Supplier	Generic Technology			
		Multi Cyclone	Filter (Baghouse)	Scrubber	ESP
1.	Turbotak Inc. 550 Parkside Drive, Unit A-14 Waterloo, Ontario N2L 5V4 Tel: 519/885-5513 Fax: 519/885-6992 Waterloo Scrubbers Att: Egbert van Everdingen Robert A. Allan			x	
2.	Joy Technologies (Canada) Inc. Precipitation Division 235 King Street East Kitchener, Ontario N2G 4N6 Tel: 519/578-6400 Fax: 519/578-8029 Att: Jim Moffat				
3.	Flakt Canada Ltd. 1400 Merivale Road Box 5060, Station F Ottawa, Ontario K2C 3P9 Tel: 613/226-3300 Fax: 613/226-1308 Att: Marijan Sever Toronto: Alan Screen Tel: 416/273-7920		x		x
4.	Pure Air [Joint Venture Mitsubishi Heavy Industries America Inc. & Air Products and Chemicals Inc.] 2 Windsor Plaza, Room 303, 2 Windsor Drive Allentown, PA 18195 Tel: 215/481-3144 Fax: 215/481-5318 Att: K. Kitamori, Vice President Technology				

TABLE 1: Suppliers of Particulate Removal Equipment
For Selected Generic Technologies

#	Supplier	Generic Technology			
		Multi Cyclone	Filter (Baghouse)	Scrubber	ESP
5.	Wheelabrator 401 Wheelabrator Way Milton, Ontario L9T 4B7 Tel: 416/844-1550 Fax: 416/875-1675 Att: Larry Martyniuk	x	x		x
6.	Wheelabrator Air Pollution Control 441 Smithfield Street Pittsburgh, PA 15222 Tel: 412/562-7010 Fax: 412/562-7254 Att: Delmar Doyle National Sales Manager Mgr. Inernational Operations	x	x		x
7.	Procedair Industries Inc. 625 President Kennedy Ave Suite 701 Montreal, Quebec H3A 1K2 Tel: 514/284-0341 Fax: 514/284-1326 Att: Bernard Cloutier [Agents for air industrie Env. of France]				
8.	Hydrosonic Systems Lone Star Steel Company Hwy 259 South P.O. Box 1420 Lone Star, Texas 75668 Tel: 214/656-6317 Fax: 214/656-6312 Att: O.L. Holland				

TABLE 1: Suppliers of Particulate Removal Equipment
For Selected Generic Technologies

#	Supplier	Generic Technology			
		Multi Cyclone	Filter (Baghouse)	Scrubber	ESP
9.	Beco Engineering Company P.O. Box 39 Glenshaw, PA 15116 Tel: 412/486-4900 Fax: 412/486-5453 Att: Dr. B.J. Lerner President				
10.	United McGill Corporation 1779 Refugee Road P.O. Box 820 Columbus, Ohio 43216 Tel: 614/443-0192 Fax: 614/445-8759 Att: Scott Frazier Precipitator Div. Sales Mgr. Steve Otero Jr. Sales Engineer Precipitator Div.				x
11.	John Zink Canada Ltd. Suite 201 801 York Mills Road Don Mills, Ontario M3B 1X7 Tel: 416/444-1145 Fax: 416/444-1053 Att: Peter Ristevski Tony Pollici				
12. a.	Research-Cottrell P.O. Box 1500 Route 22 West Somerville, NJ 08876 Tel: 201/685-4000 Fax: 201/685-4074 Att: Peter Bibbo V.P. Sales & Mktg. spoke with: Wayne Navickas				

TABLE 1: Suppliers of Particulate Removal Equipment
For Selected Generic Technologies

#	Supplier	Generic Technology			
		Multi Cyclone	Filter (Baghouse)	Scrubber	ESP
12. b.	Markham Engineering, Inc. 2624 Dunwin Drive Suite 5 Mississauga, Ontario L5L 3T5 Tel: 416/828-2002 Fax: 416/828-4531 Att: Richard Belanger [They are agents for Research-Cottrell. Send enquiry to them, copy to R-C. Att: Peter Bibbo]	x	x	x	x
13.	Ceilcote Canada Ltd. 79 Kincort Street Toronto, Ontario M6M 3E4 Tel: 416/241-8521 Fax: 416/241-2901 Att: Myron Krywonis				
14.	Hosokaw Micron Ltd. [Previously Ducon-Micropal] 1940 Steeles Avenue East Bramalea, Ontario L6T 1A7 Tel: 416/791-3883 Fax: 416/791-4839 Att: Nihal Perera				
15.	Fabricated Plastics Ltd 2175 Teston Road Maple, Ontario L6A 1T3 Tel: 416/832-8161 Fax: 416/832-2111 Att: Ken Choy				

TABLE 1: Suppliers of Particulate Removal Equipment
For Selected Generic Technologies

#	Supplier	Generic Technology			
		Multi Cyclone	Filter (Baghouse)	Scrubber	ESP

16. AAF Canada
215 Milvan Road
Toronto, Ontario M9L 2A3

Tel: 416/745-7105
Fax: 416/745-7422
Att: Mr. Graham Sims

17. Cassier Engineering Sales Ltd.,
11 Progress Ave., Unit 3,
Suite 206
Scarborough, Ontariuo M1P 4S7

Tel: 416/298-1628
Fax: 416/298-9584
Att: Mr. Bill O'Brien

18. Endur Systems Inc.
425 Enfield Road
Burlington, Ontario

Tel: 416/231-5605
Fax: 416/231-8406
Att: Mr. Bert Wierenga

19. Farr Inc.
50 East Beaver Creek Road
Unit 4
Richmond Hill, Ontario L4B 1G6

Tel: 416/632-7827
Fax: 416/632-4966
Att: Mr. Ernie Mulryne,
Branch Mgr.

TABLE 1: Suppliers of Particulate Removal Equipment
For Selected Generic Technologies

#	Supplier	Generic Technology			
		Multi Cyclone	Filter (Baghouse)	Scrubber	ESP
20.	Cantech Environmental Systems Inc. Pollution Control Division 2345 Stanfield Road Mississauga, Ontario L4Y 3Y3 Tel: 416/275-9800 Fax: 416/275-0947 Att: Mr. Michael Smith				
21.	GE Environmental Systems 200 North Seventh Street Lebanon, PA 17042 Tel: 717/274-7000 Fax: 717/274-7277 Att: Mr. Bill Morris, Mgr. of Industrial Proposals Direct Tel: 717/274-7023				
22.	Calvert Environmental Equip. Co. 5985 Sante Fe Street San Diego, CA 92109 Tel: 619/272-0050 Fax: 619/272-3672 Att: Ken Schifftner Product Manager				
23.	Watson Process Systems P.O. Box 40 Unionville, Ontario L3R 2L8 Tel: 416/475-2511 Fax: 416/475-7638 Att: Frank Watson/David Roberts			x	

TABLE 1: Suppliers of Particulate Removal Equipment
For Selected Generic Technologies

#	Supplier	Generic Technology			
		Multi Cyclone	Filter (Baghouse)	Scrubber	ESP
24.	Beltran Associates Inc. 1133 East 35th Street Brooklyn, N.Y. 11210 Tel: 718/338-3311 Fax: 718/253-9028 Att: David C. Meier Utility Sales Eng.				x
25.	Emtrol Corp. 1440 Veterans Memorial Hwy P.O. Box 365 Hauppage, N.Y. 11788 Tel: 516/582-9700 Fax: 516/234-8445 Att: Theresa Piccolino	x	x	x	x

DOC: AI911025.TBL

APPENDIX 2

DSS 8601-4
1990-10-13

1~ - Address
2~ - Fax Number

Attention: 3~:

Sir/Madam:

Re: APC Equipment for Control of Particulate Emission from Wood Fuel Fired Steam Generators - Budgetary Prices and Information as Requested

On behalf of Energy, Mines and Resources Canada, we request budget cost estimates and other information for primary and secondary APC systems for particulate abatement in flue gases produced by four (4) sizes of wood fuel-fired steam generators (see Cases 1, 2, 3 and 4 in Table 1.

1. Assumptions for Uniformity

As indicated in Figure 1 and in the attached Tables 1, 2, 3, the following assumptions have been made in the interests of uniformity for all Cases:

a. Flue gases exiting the boiler are expected to deposit particulates for reinjection in economizer, air heater or reinjection cyclone, so that loading in the flue gases entering the primary APC system should be no more than 6000 mg/Nm^3 dry.

b. The primary APC system is assumed to be a multicyclone in all cases.

c. Particulate loading in the flue gas exiting the primary APC and entering secondary APC is assumed no higher than 600 mn/Nm^3 dry.

d. The secondary APC system could be one of three options: electrostatic precipitator, baghouse or scrubber. Any of these should reduce the particulate loading in the flue gas to the compliance limit of 43 ng/J.

e. The gases exiting the secondary APC unit must comply with federal emission guidelines of 43 ng/J (0.1 lb/10^6 Btu). This works out approximately to a particulate loading of 77 mg/Nm^3 of dry flue gas [approx. 43.5 mg/Nm^3 of actual flue gas].

f. The size distribution of particulates in the flue gas shown for primary APC and secondary APC inlet conditions, Tables 2 and 3, is indicative only. Considerable variation may be anticipated in this parameter under actual operating conditions.

g. Fuel/steam efficiency in the boilers have been uniformly assumed 66% for as-fired 50% moisture content fuel, and flue gas temperature is assumed 204°C (400°F) for all cases. Both parameters will vary in practice for different facilities.

2. Request for Budgetary Costs and Other Information

Please complete the information as requested in Forms A, B, C, D, E and return - along with your equipment specifications and literature to:

A. Ismail, P.Eng.
Monenco Consultants Limited
P.O. Box 1540
One St. Paul Street
St. Catharines, Ontario L2R 7J9
Phone: 416/688-9263, Ext. 2028
Fax : 416/688-0921
Please telephone if you have questions.
Please send Forms A to E by telefax if possible, originals by mail.

We thank you in anticipation of your cooperation.

Sincerely,

A. Ismail, P.Eng.
Head of Advanced Energy Technology
AI/lp

FIGURE 1

SCHEMATIC ARRANGEMENT OF
WOOD FIRED BOILER AND APC SYSTEM

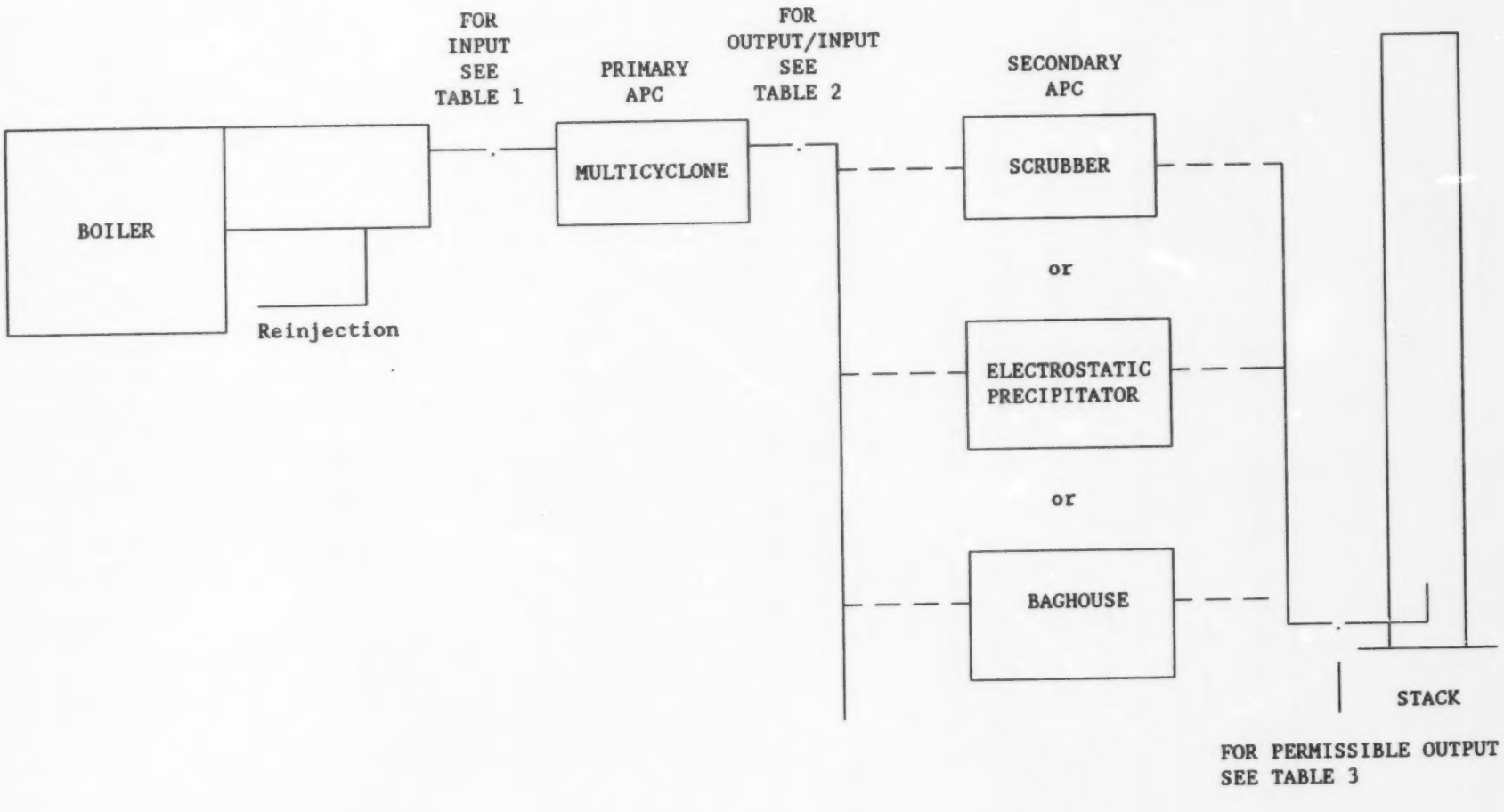

TABLE 1

Case	Boiler Capacity		Flue Gas Volum @ 50% Excess Air 204°C (400°F)	Moisture in Flue Gas Wt. %
	Fuel In odMg/h(GH/h)	Steam Out GJ/h(10^6Btu/h	m^3/h (ft^3/h)	
1	1.15(22.76)	15(14.2)	18,700 (0.66 x 10^6)	13 - 15
2	3.07(60.61)	40(37.9)	50,000 (1.76 x 10^6)	13 - 15
3	7.66(151.5)	100(94.7)	125,000 (4.4 x 10^6)	13 - 15
4	22.97(454.55)	300(284)	374,000 (13.2 x 10^6)	13 - 15

Note: Boiler efficiency is uniformly assumed 66% when firing 50% moisture content wood fuel with HHV = 19.79 GJ/odMg (8500 Btu/odlb).

odMg = oven-dried metric tonne.
As-fired HHV of "green" wood fuel = 9.89 GJ/Mg (4250 Btu/lb).

TABLE 2

Approximate typical particle size distribution at inlet to multicyclone (see Figure 1):

μm	%
>16	44
16-9	25
9-6	10
6-4	7
4-1.5	5
1.5-1	3
1-0.5	3
<0.5	3

The loading at inlet to multicyclone is expected to vary 2,000 mg/Nm^3 to 6,000 mg/Nm^3 dry.

The required particle emission loading at outlet from multicyclone is expected to be 300 mg/Nm^3 - 600 mg/Nm^3 of dry flue gas.

Flue gas is assumed at 204°C (400°F) uniformly for all Cases.

TABLE 3

Approximate typical particle size distribution at inlet to scrubber/ESP/baghouse (see Figure 1):

μm	%
>14	5
14-9	6
9-6	8
6-4	21
2-1	21
1-0.5	24
<0.5	15

The loading at inlet to equipment will be 300 mg/Nm^3 - 600 mg/Nm^3 dry.

The required particle emission loading at outlet of ESP/scrubber/baghouse is 43 ng/J (0.1 lb/million BTU fired).

Flue gas is assumed at 204°C (400°F) uniformly for all Cases.

FORM A

The enclosed APC system information in Forms B, C, D, E is provided by:

Company Name
& Address :

Telephone :

Telefax :

Contract Person's Name:

Title :

Or Attach Business Card:
(Containing Above Information)

Forms A, B, C, D, E should be telefaxed (and originals mailed) to:

A. Ismail, P.Eng.
Monenco Consultants Limited
P.O. Box 1540
One St. Paul Street
St. Catharines, Ontario L2R 7J9
Phone: 416/688-9263, Ext. 2028
Fax : 416/688-0921

Please telephone if you have questions.

Please send Forms A to E by telefax if possible, originals by mail.

FORM B

Data for Primary APC Unit: Multicyclone

Case	Ex-Works Cost	Installation [1]	Installed Cost [1]	Foot Print Dimensions Meters			Weight
	1990 C$	%	C$	L	W	H	kg
1							
2							
3							
4							

	Utility Requirements				
	Electricity		Water	Other	Specifications (List Attached Specifications)
	Connected kW	Consumption kW	m^3/h	(Specify)	
1					
2					
3					
4					

[1] Please estimate for Southern Ontario

FORM C

Data for Secondary APC Unit: Electrostatic Precipitator (ESP)

Case	Ex-Works Cost	Installation [1]	Installed Cost [1]	Foot Print Dimensions Meters			Weight
	1990 C$	%	C$	L	W	H	kg
1							
2							
3							
4							

	Utility Requirements				
	Electricity		Water	Other	Specifications (List Attached Specifications)
	Connected kW	Consumption kW	m^3/h	(Specify)	
1					
2					
3					
4					

[1] Please estimate for Southern Ontario

FORM D

Data for Secondary APC Unit: Baghouse

Case	Ex-Works Cost	Installation [1]	Installed Cost [1]	Foot Print Dimensions Meters			Weight
	1990 C$	%	C$	L	W	H	kg
1							
2							
3							
4							

	Utility Requirements				
	Electricity		Water	Other	Specifications (List Attached Specifications)
	Connected kW	Consumption kW	m^3/h	(Specify)	
1					
2					
3					
4					

[1] Please estimate for Southern Ontario

FORM E

Data for Secondary APC Unit: Scrubber

Case	Ex-Works Cost	Installation [1]	Installed Cost [1]	Foot Print Dimensions Meters			Weight
	1990 C$	%	C$	L	W	H	kg
1							
2							
3							
4							

	Utility Requirements				
	Electricity		Water	Other	Specifications (List Attached Specifications)
	Connected kW	Consumption kW	m^3/h	(Specify)	
1					
2					
3					
4					

[1] Please estimate for Southern Ontario

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